USD(R&E)

Leveraging Architecture to Inform the Design of Simulation Experiments for Mission Engineering Studies

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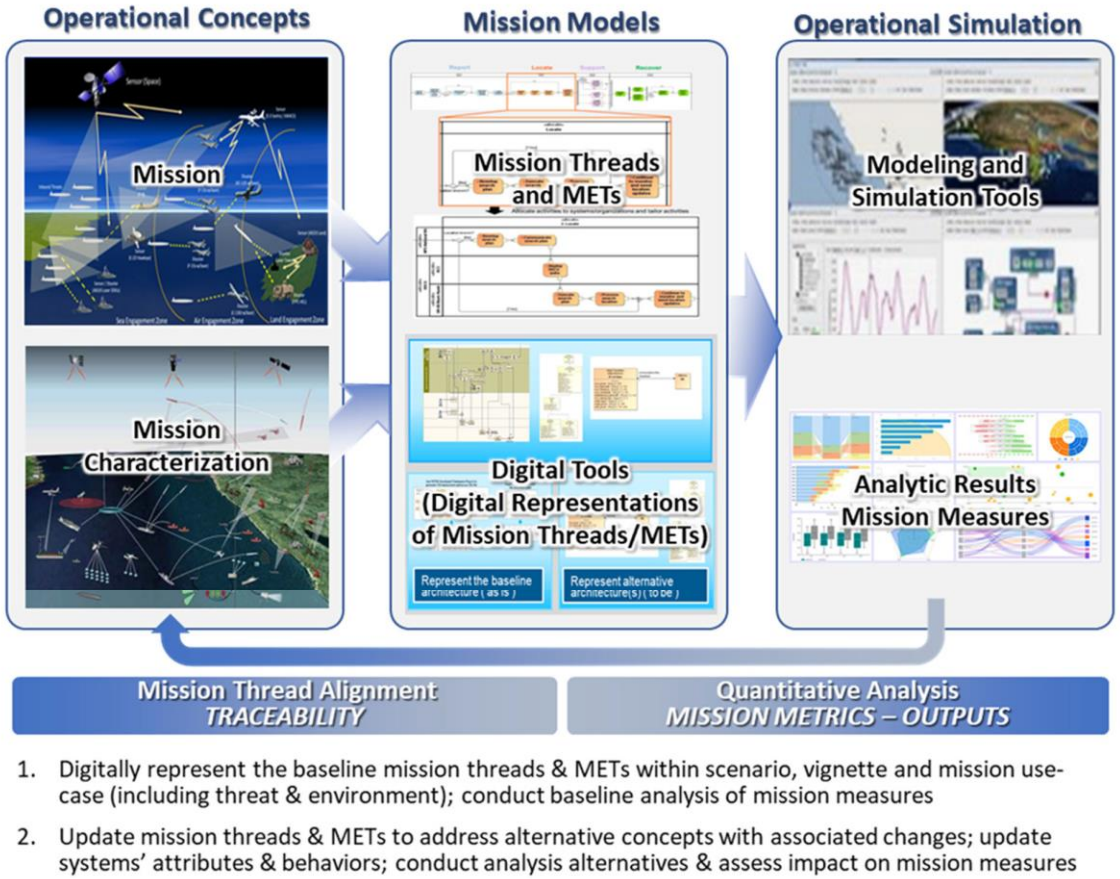
Mission Integration's Challenge

- Traditional approaches to engineering analysis and experimentation focus on answering specific system performance questions
  - E.g., What type of wing design will give my aircraft the greatest range?
- In contrast, Mission Integration (MI) builds portfolios of investments to improve mission performance under a variety of circumstances
  - What set of technologies should DoD mature to improve the performance of mission X?
- Interactions between investment options becomes critical
  - An advanced sensor and an advanced weapon may not have impact by themselves, but put to them together…

Mission Integration Workflow

- Evaluate candidate technologies by integrating them into a realistic mission architecture
  - Often done through constructive simulation
  - These simulations can be computationally expensive



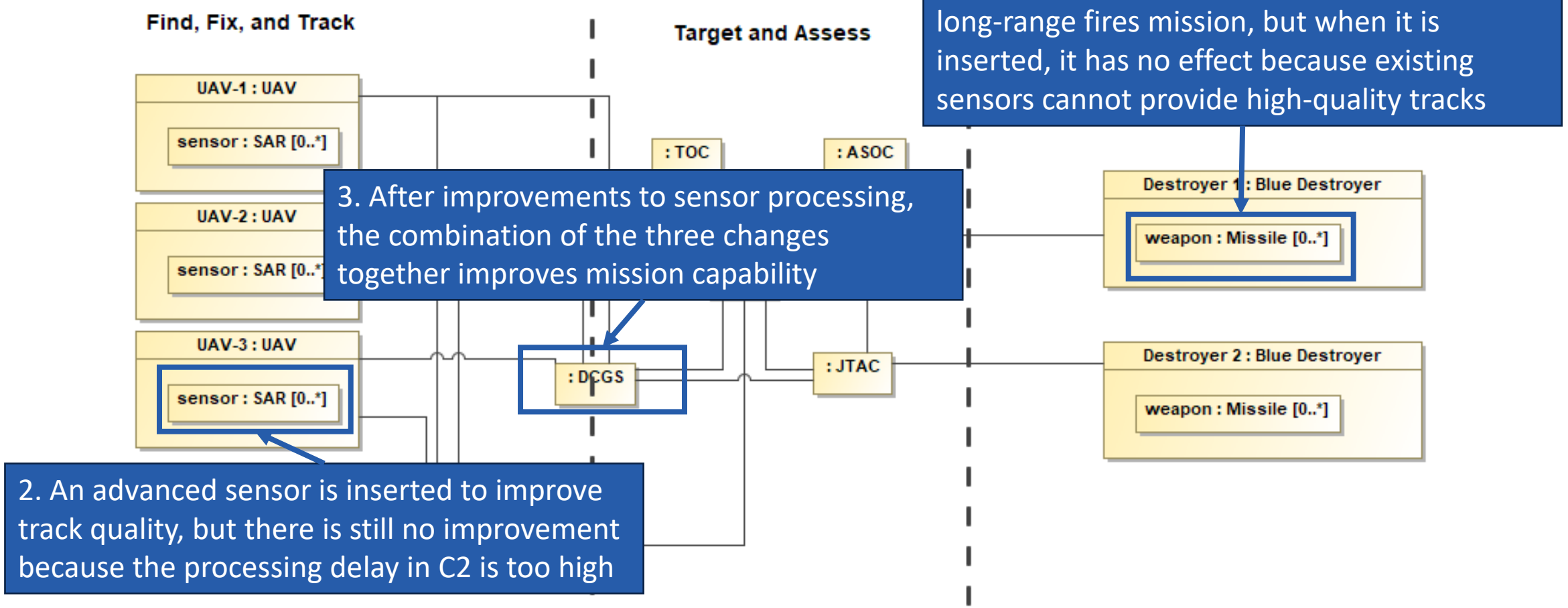
1. Digitally represent the baseline mission threads & METs within scenario, vignette and mission use-case (including threat & environment); conduct baseline analysis of mission measures
2. Update mission threads & METs to address alternative concepts with associated changes; update systems' attributes & behaviors; conduct analysis alternatives & assess impact on mission measures

Source: Department of Defense Mission Engineering Guide, Version 2.0, October 1, 2023, DOPSR #23-S-3518

Why is this a challenge?

- Mission Integration often considers a very large number of investment options
  - About 50 candidate technologies at a time
  - A naïve full factorial experimental design on 50 options means a run matrix of over 112 trillion cases
- Traditional approaches to reducing the size of an experimental design sacrifices information on interaction effects
- But in Mission Integration we are often looking for interaction effects

Why interactions matter



IBD Source: Goldenberg, Marc, Reusable Digital Engineering Environment to Support Mission Engineering Studies, 2021 NDIA Systems and Mission Engineering Conference, DOPSR #22-S-0345

How is this handled today?

- To date, MI has used a mixture of expert judgement and some criteria-based methods to down-select to a reasonable run-matrix
- Even if done well, it is hard to justify the results to external stakeholders
  - “Why didn’t you study my technology?”
- Need a systematic approach to make MI’s decisions more defensible
  - Also reduces the chance that an important investment was missed

Three Areas for Investigation

1. Better understand the gaps and opportunities in the baseline
   - Adapt existing approaches for analyzing large constructive simulations

2. Systematically select which technology options are introduced
   - Mission engineering introduces challenges to traditional approaches
   - Develop ME specific approach using data from past MI studies

3. Evaluate analysis results in the context of the whole portfolio
   - Adapt existing approaches from decision and portfolio analysis

Idea: Use the Mission Architecture to Guide the DoE

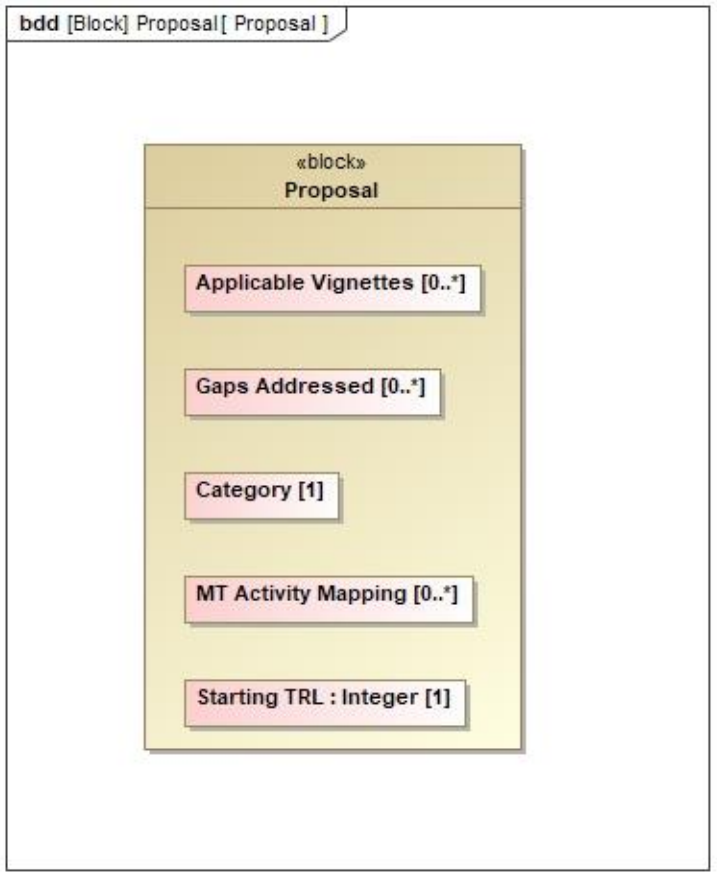
- Use mission architecture to identify complementary technologies
  - Technologies that work together to close a kill chain are complements
  - Complements are more likely to be significant from a DoE perspective
- Three perspectives are used to identify viable bundles of options
  - Functional, Structural, and Portfolio
- Surrogates and duplicates can be used for risk reduction
- Performing analysis using the architecture reduces costs
  - Options are eliminated before building expensive simulation models

Research Approach

- Constructed filters based on experience from past MI studies
- Tested the filters on a recent batch of technology proposals and associated baseline architecture
  - Interactions were kept unless there was enough evidence to remove them
  - Found that too few interaction cases were filtered out
- Transitioned to a set of bundling rules
  - Bundles only added to experimental design if sufficient evidence
- Tested revised bundling rules on two historical MI data sets

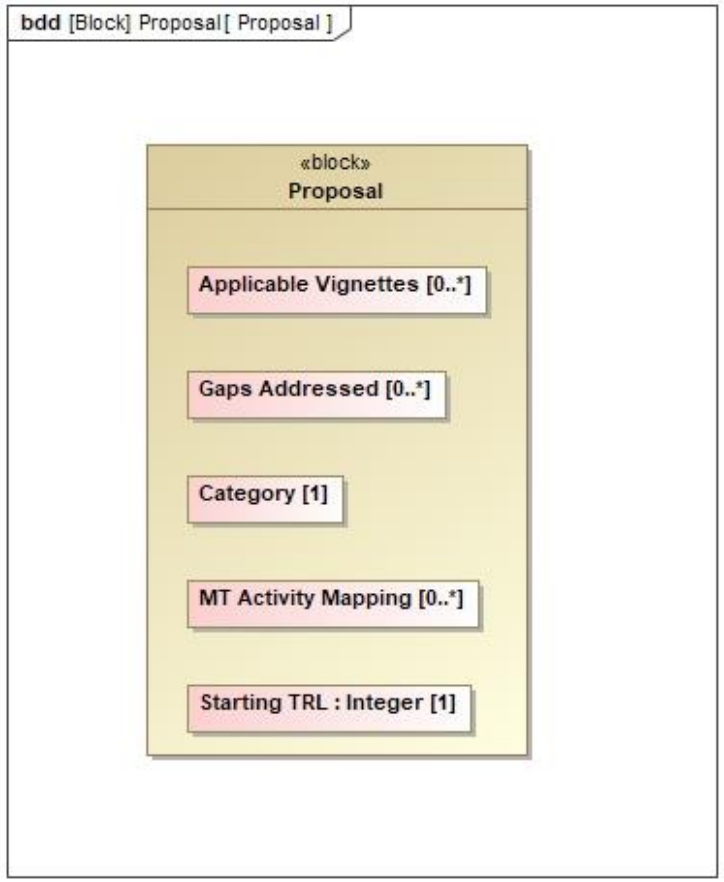
Defining a Proposal

- Proposal attributes:



- A proposal maybe be applied to more than one vignette
- A proposal may address more than one gap
- Assigned one of three categories: Functional, Structural, or Hybrid
- Functional and hybrid proposals are also mapped to applicable activities in the mission thread

Applying Bundling Rules



- Must apply to the same vignette to be candidates for bundling
- Two types of bundling operations:
  1. Pair functional proposals with enabling structural proposals
  2. Pair functional proposals that complement in each other in the mission thread
- Limited bundle size using the probability of realization
  - Derived from TRLs

Bundling 1 – Pairing Structural and Functional Proposals

Proposal Name	Proposal ID	Applicable Vignettes	Gaps	TRL	Category	MT Activity
proposal_13	p013	B	G1	3	Structural	
proposal_51	p051	B	G1	5	Structural	
proposal_83	p083	B	G1	3	Structural	
proposal_34	p034	B	G1	9	Hybrid	Engage
proposal_85	p085	B	G2	4	Structural	
proposal_19	p019	B	G2	4	Structural	
proposal_22	p022	B	G2	3	Structural	
proposal_15	p015	B	G2	5	Functional	Engage
proposal_48	p048	B	G2	5	Hybrid	Track
proposal_54	p054	B	G2	9	Structural	
proposal_71	p071	B	G2	3	Functional	Assess
proposal_77	p077	B	G2	9	Functional	Track
proposal_9	p009	B	G2	4	Structural	
proposal_87	p087	B	G2	5	Hybrid	Assess
proposal_88	p088	B	G2	3	Functional	Track
proposal_6	p006	B	G3	4	Functional	Engage
proposal_25	p025	B	G3	8	Functional	Engage
proposal_29	p029	B	G3	6	Structural	
proposal_84	p084	B	G3	6	Hybrid	Engage
proposal_70	p070	B	G3	8	Functional	Find
proposal_75	p075	B	G3	3	Functional	Target
proposal_26	p026	B	G4	4	Structural	
proposal_68	p068	B	G4	8	Structural	
proposal_38	p038	B	G4	7	Structural	
proposal_81	p081	B	G4	5	Functional	Target
proposal_7	p007	B	G5	8	Functional	Target
proposal_46	p046	B	G5	4	Functional	Engage
proposal_42	p042	B	G5	6	Hybrid	Find

Bundle A

Proposal ID	TRL
p085	4
p015	5
p071	3
p077	9
p088	3

Bundle of a structural proposal with functional proposals that address same or related Gaps.

Bundle A1

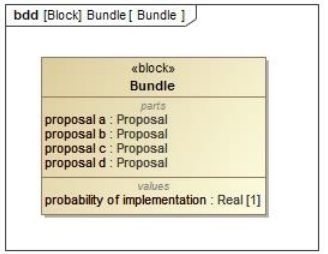
Proposal ID	TRL
p085	4
p015	5
p077	9

Bundle A2

Proposal ID	TRL
p085	4
p071	3

Bundle A3

Proposal ID	TRL
p085	4
p088	3



Bundle B

Proposal ID	TRL
p054	9
p015	5
p071	3
p077	9
p088	3

Bundle B1

Proposal ID	TRL
p054	9
p015	5
p077	9

Bundle B2

Proposal ID	TRL
p054	9
p071	3

Bundle B3

Proposal ID	TRL
p054	9
p088	3

Premise: new functions may require new architectural components to realize their full benefit to the kill chain.

Bundling 2 – Pairing Functional Proposals

Proposal Name	Proposal ID	Applicable Vignettes	Gaps	TRL	Category	MT Activity
proposal_32	p032	C	G1	6	Hybrid	Find
proposal_39	p039	C	G1	7	Functional	Engage
proposal_53	p053	C	G1	7	Structural	
proposal_66	p066	C	G1	7	Hybrid	Find
proposal_13	p013	C	G1	6	Structural	
proposal_26	p026	C	G1	8	Hybrid	Target
proposal_10	p010	C	G2	4	Structural	
proposal_12	p012	C	G2	7	Structural	
proposal_75	p075	C	G2	8	Hybrid	Fix
proposal_7	p007	C	G2	9	Hybrid	Assess
proposal_8	p008	C	G2	7	Structural	
proposal_62	p062	C	G2	5	Structural	
proposal_79	p079	C	G2	7	Hybrid	Track
proposal_28	p028	C	G2	9	Structural	
proposal_5	p005	C	G3	8	Hybrid	Assess
proposal_23	p023	C	G3	5	Functional	Fix
proposal_14	p014	C	G3	7	Functional	Find
proposal_52	p052	C	G3	9	Hybrid	Assess
proposal_63	p063	C	G3	5	Functional	Track
proposal_67	p067	C	G3	4	Hybrid	Find
proposal_47	p047	C	G4	6	Structural	
proposal_73	p073	C	G4	4	Structural	
proposal_43	p043	C	G5	7	Functional	Target
proposal_45	p045	C	G5	7	Hybrid	Track
proposal_46	p046	C	G5	4	Hybrid	Engage

Bundle A

Proposal ID	TRL	MT Activity
p032	6	Find
p075	8	Fix
p079	7	Track
p026	8	Target
p039	7	Engage
p007	9	Assess

Bundle B

Proposal ID	TRL	MT Activity
p066	7	Find
p075	8	Fix
p045	7	Track
p043	7	Target
p039	7	Engage
p005	8	Assess

Bundle C

Proposal ID	TRL	MT Activity
p067	4	Find
p023	5	Fix
p063	5	Track
p043	7	Target
p046	4	Engage
p052	9	Assess

Bundle C1

Proposal ID	TRL	MT Activity
p067	4	Find
p023	5	Fix

Bundle C2

Proposal ID	TRL	MT Activity
p023	5	Fix
p063	5	Track

Bundle C3

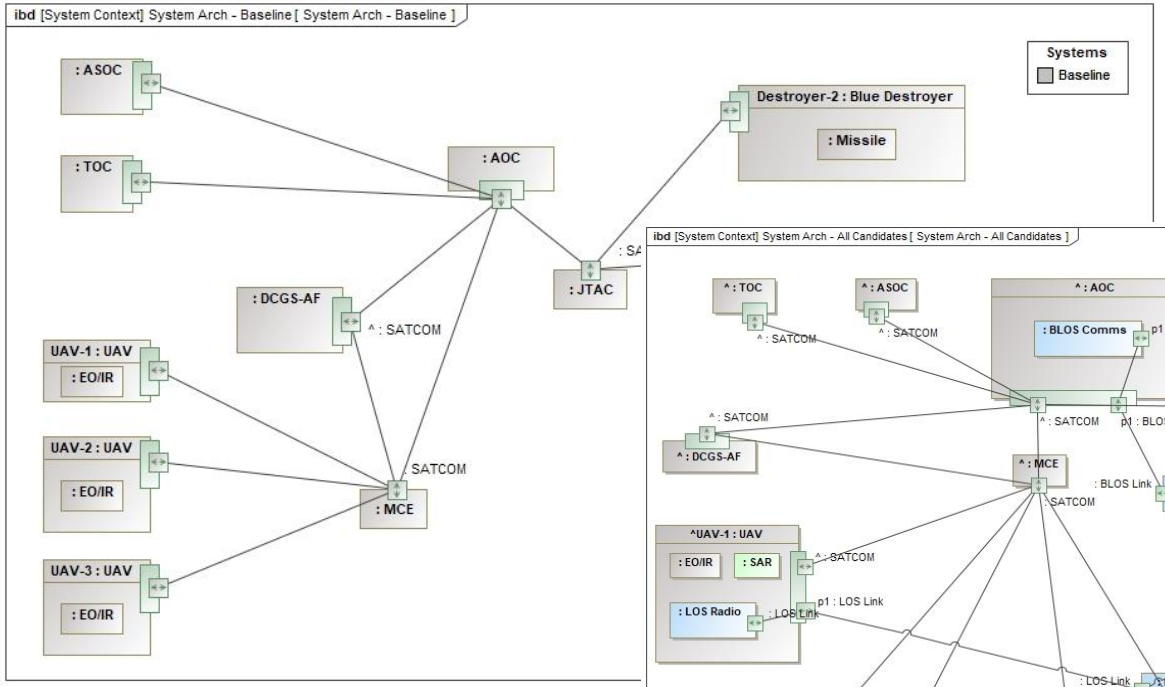
Proposal ID	TRL	MT Activity
p063	5	Track
p043	7	Target

Bundle C4

Proposal ID	TRL	MT Activity
p043	7	Target
p046	4	Engage

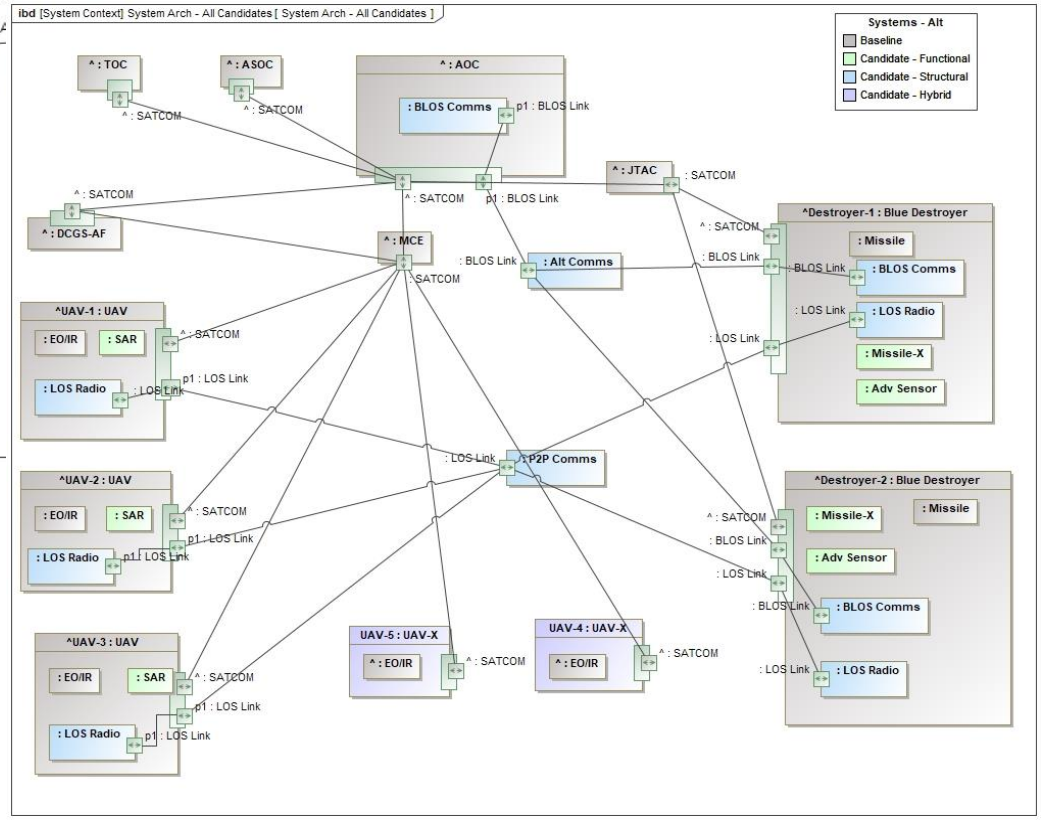
Premise: a functional proposal may be enhanced or enabled by improvements in other functional aspects of the kill chain.

Notional Example of Bundling – Step 1



Baseline

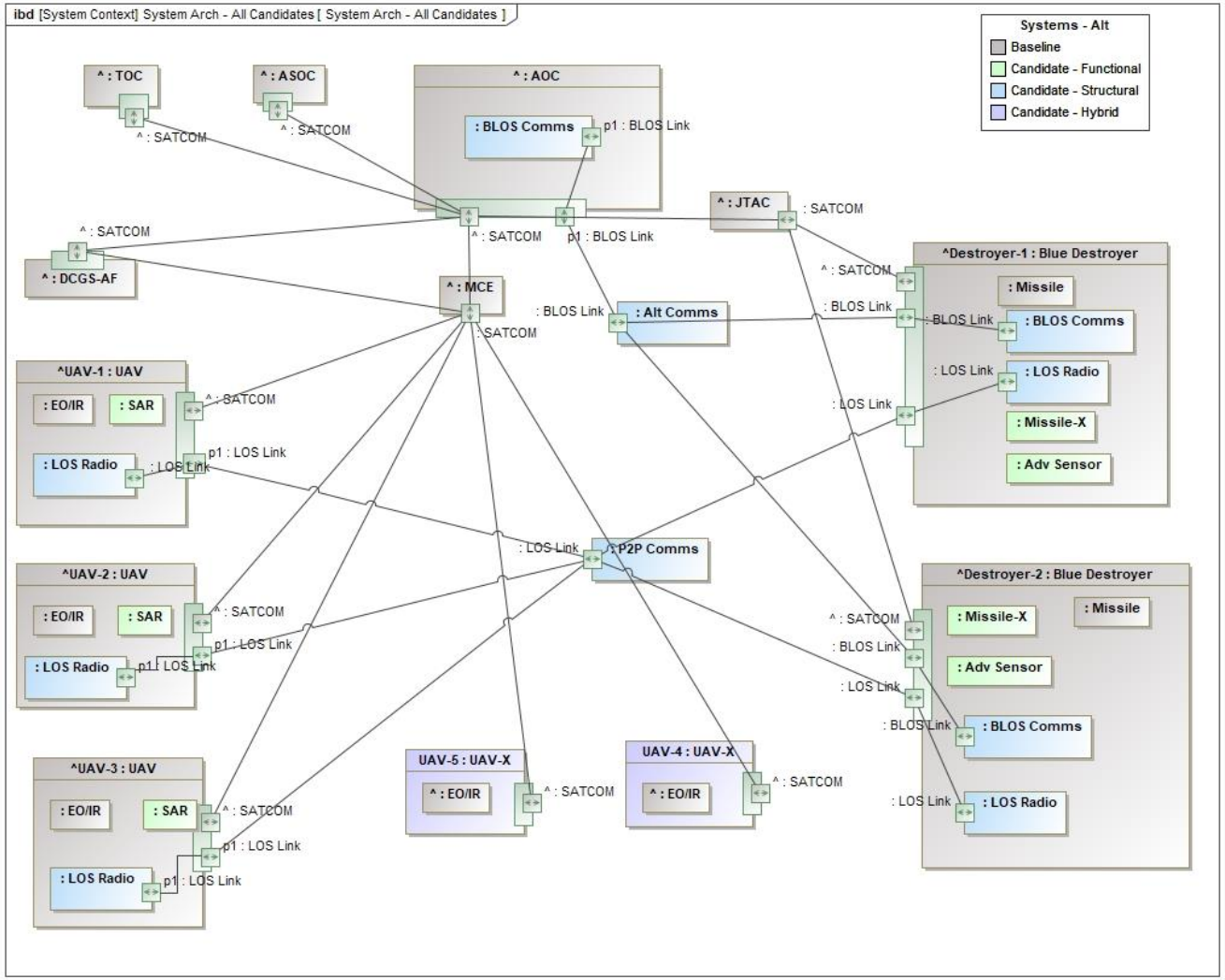
Baseline + All candidates that apply to the mission scenario / vignette



- Proposed technologies are mapped to the baseline architecture and assigned a category

IBD adapted from : Goldenberg, Marc, Reusable Digital Engineering Environment to Support Mission Engineering Studies, 2021 NDIA Systems and Mission Engineering Conference, DOPSR #22-S-0345

Notional Example of Bundling – Step 2



- Use the architecture to
  - Find functional proposals that may need structural proposals for closure
  - Find functional proposals that may complement each other in execution

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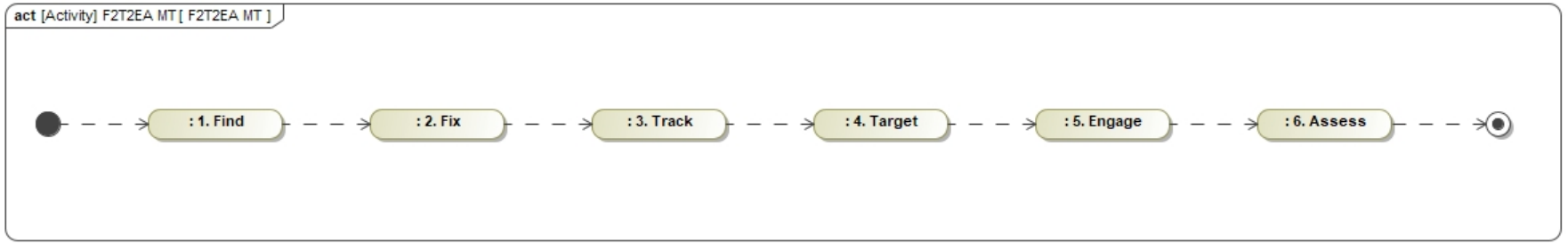
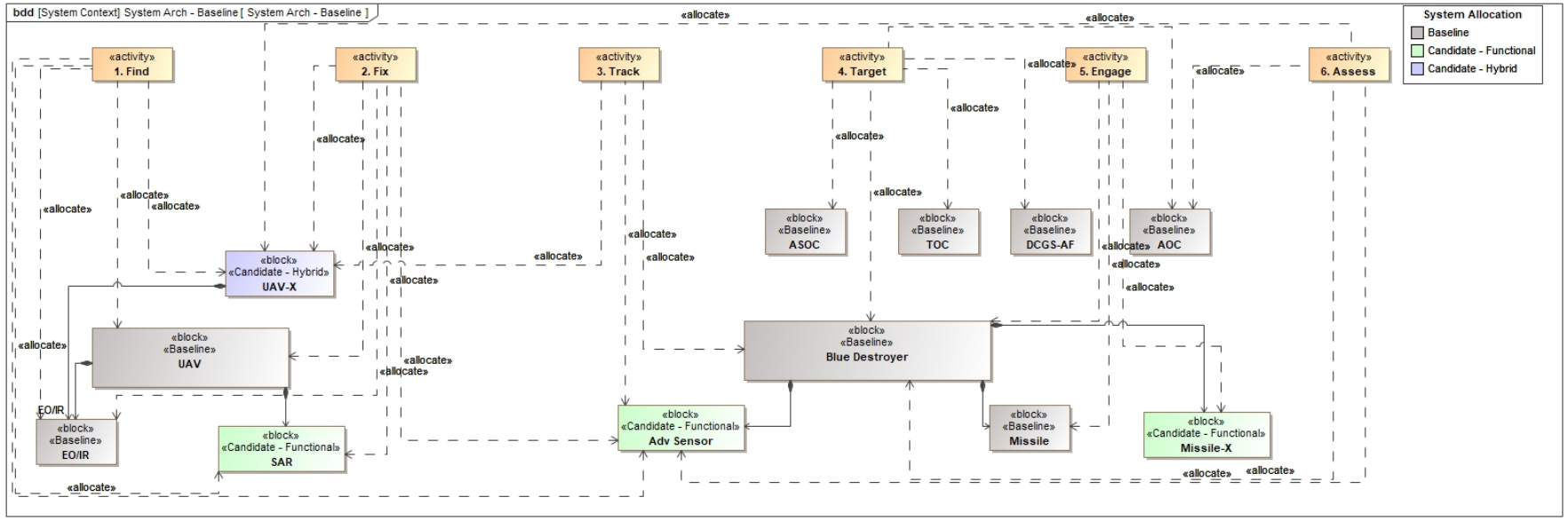
Notional Example of Bundling – Step 3

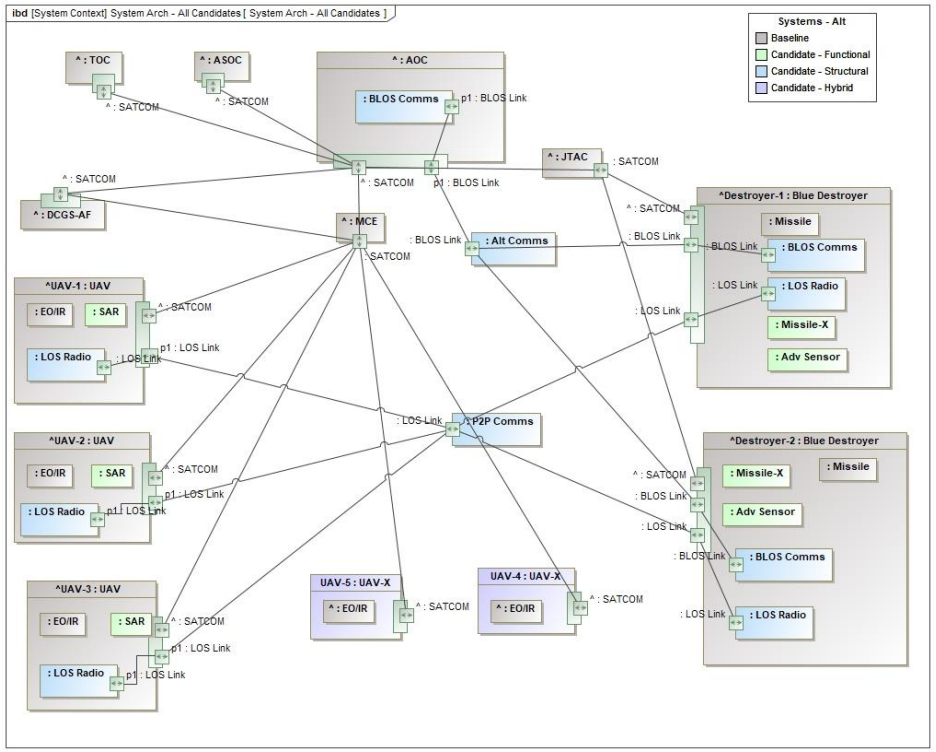




- Use the Mission Thread for the vignette to:
  - Identify the functional contribution of technology proposals

BDD adapted from : Goldenberg, Marc, Reusable Digital Engineering Environment to Support Mission Engineering Studies, 2021 NDIA Systems and Mission Engineering Conference, DOPSR #22-S-0345

Notional Example of Bundling – Step 4



Proposal ID	Candidate Name	Category	MT Alignment	Gap	Applicable Scenario	TRL
p001	Alt Comms	Structural	N/A	1	A	5
p002	P2P Comms	Structural	N/A	2	A	8
p003	SAR Sensor	Functional	Find, Fix	2	A	7
p004	UAV-X	Hybrid	Find, Fix, Track, Assess	1, 3	A	4
p005	Adv Sensor	Functional	Find, Fix, Track, Assess	2, 3	A	6
p006	Missile-X	Functional	Engage	4	A	8

Candidate Name	Category	TRL
Alt Comms	Structural	5
UAV-X	Hybrid	4

Candidate Name	Category	TRL
Alt Comms	Structural	5
Adv Sensor	Functional	6
Missile-X	Functional	8

Candidate Name	Category	TRL
Alt Comms	Structural	5
SAR Sensor	Functional	7
Missile-X	Functional	8

Candidate Name	Category	TRL
P2P Comms	Structural	8
SAR Sensor	Functional	7
Adv Sensor	Functional	6
Missile-X	Functional	8

Candidate Name	Category	TRL
UAV-X	Hybrid	4
Adv Sensor	Functional	6

Candidate Name	Category	TRL
UAV-X	Hybrid	4
Missile-X	Functional	8

Candidate Name	Category	TRL
UAV-X	Hybrid	4
SAR Sensor	Functional	7

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Lessons Learned to Date

- The first attempt at applying the filters was too conservative
- The revised rules did a better job of reducing the number of bundles from a full factorial design
- but challenges remain
  - Requires a detailed baseline architecture to effectively differentiate among options
  - The breadth of the gaps in the current data sets make it challenging to down select
  - Does not account for interactions with the threat architecture
  - TRLs by themselves do not provide a strong indicator of probability of transition

Future Work

- Finish refining and testing the rules on the historical studies
- Modify the rules to integrate threat architectures
- Expand the set of data used to assess maturity and transition risk
- Build scripts to automate aspects of the bundling rules in the architecture tool
- Implement the approach on a future MI technology evaluation study